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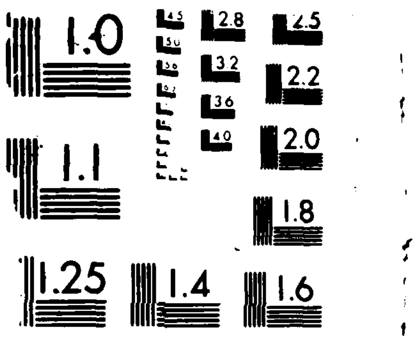

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MADIDA--MAINTENANCE AND DIAGNOSTIC INTELLIGENT DECISION AID

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New demands are being made on current automatic test equipment environments that encourage personnel in the maintenance and diagnostic arena to explore recent advances in artificial intelligence technology. There is a growing demand to design user-friendly, portable, cost effective, state of the art computer controlled diagnostic test procedures. Currently there are two types of diagnostic test systems, manual and automatic testing. MADIDA (maintenance and diagnostic intelligent decision aid) provides a mixture of automated and (cont)

20. ABSTRACT (cont)

manual diagnostic test procedures. This system promises maintenance and diagnostic personnel with an alternative tool which can be used in conjunction with existing tools or as a stand-alone intelligent decision aid system. The tool also has very desirable development and implementation characteristics.

CONTENTS

INTRODUCTION

The degree of sophistication of Army fire control on-board electronic systems has increased dramatically during the post-Vietnam era. During the 1980s, the Army Modernization Program has sought to use state-of-the-art mini and microcomputer technology to a maximum. Some systems that exemplify this policy include the ABRAMS tank, the Bradley Fighting Vehicle, the SGT York Division Air Defense Gun, and the APACHE helicopter. Maintenance manuals for a tank can require 60,000 pages of documentation. Given this increase in complexity, there exists a corresponding need to provide tools to deal with the maintenance of these systems.

A major expert system currently under development in the maintenance and diagnostic environment is BITE (United States Army). BITE is an all encompassing electronic malfunction diagnostic system for combat ground vehicles. The date of delivery is 1990. One of the contributions of BITE will be to study two different user interface techniques: audible information and visual display. MADIDA (maintenance and diagnostic intelligent decision aid), the system presented in this report, could make a contribution to BITE.

Current Approaches to Diagnostics

Current procedures for the isolation of faults in electronic components fall between two extremes. On one extreme, diagnostic stations consist of large collections of tools and fault manuals. This approach is essentially a manual test procedure. On the other extreme, computer-controlled test equipment, driven by highly specialized programs, are used in an attempt to completely remove the technician from the diagnostic process. The manual process requires skilled personnel while automation is very expensive and as changes occur in components, test programs can be rendered useless and must be reprogrammed at great expense. Most successful diagnostic environments contain a mix of both manual and automated strategies. The mix is usually dictated by the cost of automation and the availability of skilled personnel.

Looking at testing from the AI/Expert Systems perspective, a test procedure can be viewed as a sequence of calls to stimulus-response procedures. The order of these calls is driven by component-specific if-then rule sets.

In their most primitive form, these test procedures are paperbound manuals which provide detailed specifications consisting of schematics and sequences of input/output reading on test points on the unit under test (UUT). Automatic test equipment (ATE), called test program sets, are collections of hardware and software that provide high-level functions to perform stimulus-response I/O with the UUT.

Problems With Current ATE Environments

One important problem with existing ATE environments is the uncontrollable cost associated with the development of required hardware and software. There is difficulty in all areas of software development, to properly forecast software and hardware costs, but especially in the maintenance and diagnostic domain, due to complexity. Other major problems with existing ATE are as follows:

1. Lack of portability of the resulting systems

2. The required hardware and software for current ATE environments is too cumbersome and rigid for future needs. The ATE environment of the future will require compact hardware and manageable software.

3. Current ATE systems lack a standard maintenance and diagnostic software development process. The complexity of the maintenance and diagnostic domain forced personnel to produce expert-like systems which incorporated and maintained the large and complex knowledge bases before there were good tools available. This situation was further complicated when expert system development tools became available, because there was, and still is, a resistance to convert from the traditional though cumbersome ATE environments to an environment which embodies advances in recent AI technology. Although such resistance is a common human trait, it cannot withstand the economic pressures of today's Army.

AI/Expert Systems and Tool Selection

To improve the performance and reduce the cost of current ATE environments, it is necessary to incorporate AI/Expert System technology into maintenance and diagnostic activities.

Expert systems consist of a knowledge base, a control strategy, and an inference engine. The knowledge base is developed by a knowledge engineer who extracts rules or examples from the domain expert. The control strategy selects from among the various rule sets to establish the validity of a premise. The inference engine is the low-level reasoning strategy or pattern matching technique for deciding which knowledge to use when making decisions.

The experience gained from constructing expert systems indicates that knowledge base development is the key to an effective expert system. A number of approaches to knowledge acquisition have been tried (ref 1) but all have been extremely time consuming. The easiest form of knowledge acquisition for both the knowledge engineer and the domain expert is by example. Therefore, an important decision in the development of an expert system is to use an expert system development tool which allows the construction of the data base by means of examples. RuleMaster (ref 2) is an expert system development tool which allows this type of

knowledge acquisition. For this reason and many others, RuleMaster was chosen as the starting point for the development of the MADIDA system.

DISCUSSION

Relevant Literature

There are several research studies that are relevant: Joint Services Workshop on Artificial Intelligence in Maintenance (ref 3) and SRI/Army Study (ref 4); expert system development is presented in reference 1; surveys of expert systems and ATE applications can be found in references 5 through 10; and the inductive approach to knowledge acquisition is discussed in references 2 and 11.

MADIDA

MADIDA is a project started in 1986. The overall project goal is to embed recent advances from artificial intelligence research into a user-friendly maintenance and diagnostic development environment. The system presently performs diagnostic test procedures to isolate faulty pins and channels in a circuit board.

This year's project goal was to research and develop a system framework that integrates a graphics subsystem (*containing its own* data base) into a data base of rule sets generated from examples provided by experts.

The procedures for the isolation of faults in components fall between two extremes: manual testing and automatic testing. This spectrum of fault diagnosis, from no automation testing to computer-controlled testing, does not provide the versatility needed to cost effectively diagnose circuit boards. MADIDA is an environment which can be used to offer the maintenance and diagnostic personnel an alternative that allows facilities to incorporate various degrees of automation throughout their activities.

Where MADIDA and ATE Fit Into the Maintenance and Diagnostic Domain

The most popular maintenance and diagnostic tool presently being used in this area is ATE. Presently MADIDA can be used as a stand-alone system and in the future can be made to work in conjunction with the automatic test equipment used to diagnose circuit boards.

The MADIDA system can be used in three different areas of the maintenance and diagnostic domain.

1. Environments where ATE does not exist. Those facilities do not find it cost effective to buy ATE environments because even though they diagnose

a large number of boards, they do only a small quantity of each board type. MADIDA would be a cost effective alternative to those ATE environments, costing approximately $2,000* for a microcomputer (IBM-PC or compatible), $700 for a graphics package (GKS), and $4,500 for RuleMaster, for a minimum system.

2. Existing ATE environments. ATLAS programs (software that runs on ATE) perform fault diagnosis on boards down to a predefined diagnostic test procedure. The level of diagnosis is dependent on the amount a facility is willing to spend on the development of hardware and software for the ATE. MADIDA could take the results from ATLAS programs and run diagnostic test procedures to go one level beyond the ATLAS program.

3. Maintenance and diagnostic domain where ATE exists for some boards but would not be cost effective to have all boards analyzed by ATE. MADIDA could perform diagnostic test procedures on boards that would not be cost effectively analyzed by ATE.

MADIDA Architecture

The system architecture for the MADIDA system will be discussed in two parts: (1) diagnostic rule subsystem and (2) the graphics support system (fig. 1).

1. Diagnostic rule subsystem consists of four basic modules:

- Sets of examples
- Induction algorithms
- Rule base
- Uncertainty functions

The set-of-examples module consists of the collection of examples given by maintenance and diagnostic experts. These instances can be nonmonotonic in nature, allowing the expert to associate degrees of uncertainty with the examples. The induction-algorithms module produces a knowledge base of rules from the data provided in the set-of-examples module. Quinlan's ID3 algorithm (ref 11) is used to produce the hierarchy of decision trees from the given examples. The rule-base module contains the sets of rules generated from the induction algorithms. Both forward and backward chaining control strategies are applied to these rules during the various diagnostic test procedures. The uncertainty-functions module applies degrees of uncertainty to the rules in the knowledge base, using an inference network to reason about the likelihood of the hypotheses.

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* Money referred to is in FY 86 dollars.

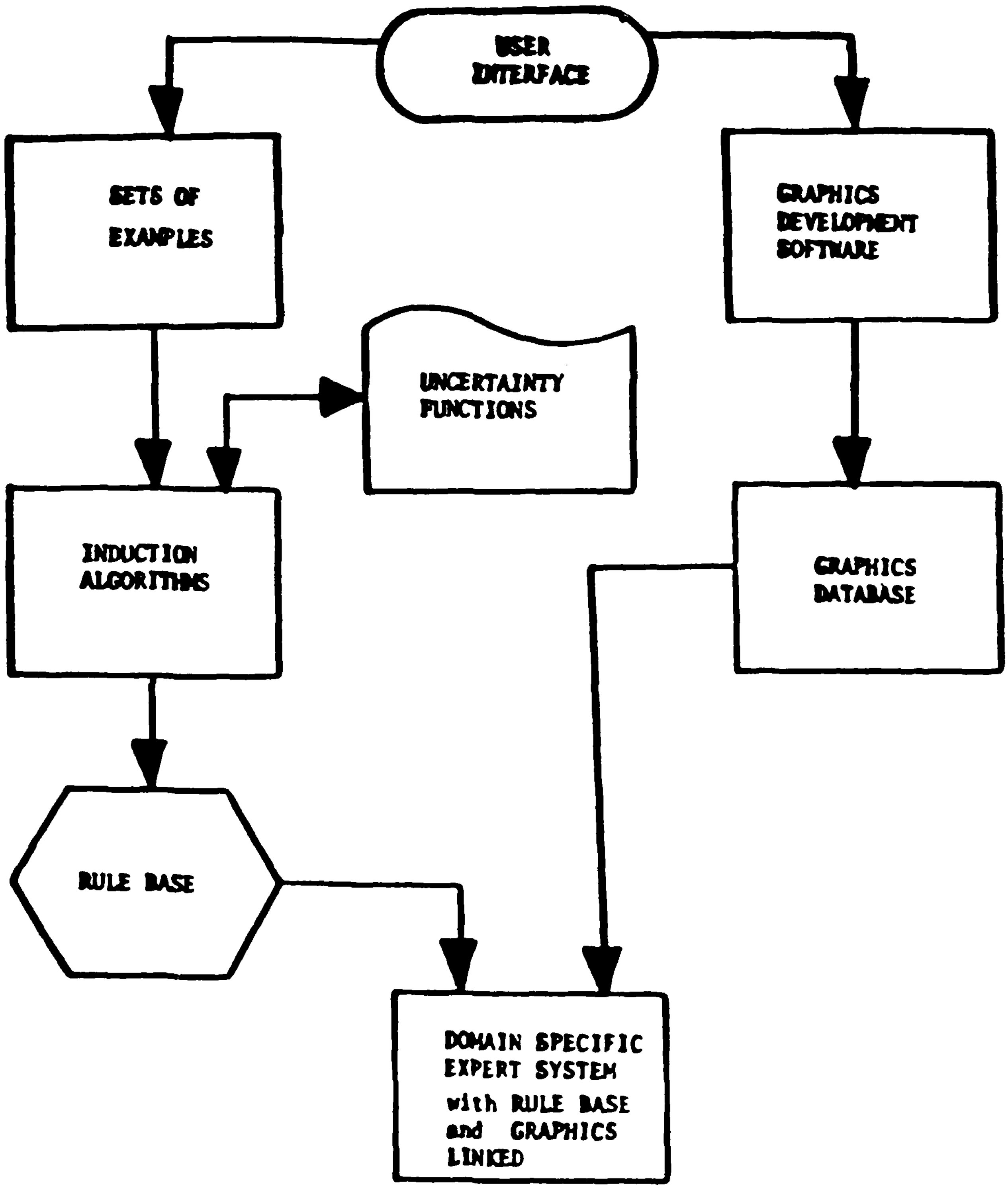

Figure 1. System architecture diagram

the Radian Corporation, was used to generate MADIDA's rule base from maintenance and diagnostic expert examples.

MADIDA's rule base consists of 135 leaf-nodes. Each leaf-node can be viewed as one (fairly complex) rule. The graphics support package consists of 1200 lines of C source, and the graphics development package consists of 2500 lines of C source code.

Attributes of RuleMaster

RuleMaster, a generic expert system building tool developed by the Radian Corporation of Austin, Texas, was chosen for this project. It offered many of the qualities that were felt would be necessary for the development of a successful maintenance and diagnostic expert system.

The first concern was to use a tool that could generate knowledge bases from examples given by domain experts. This induction process is an important concept in expert system development, since experts best describe their knowledge through examples. RuleMaster uses Quinlan's ID3 algorithm (ref 10) to generate rules from examples, narrowing the gap between knowledge engineer and the domain expert. The second concern was to build a working tool that could be ported to a wide range of computer systems. RuleMaster has been ported to over 60 computers ranging from micros to mainframes. The third concern was to build a system which had the ability to interface with other languages, computers, hardware, knowledge bases, graphics packages, etc. RuleMaster gives us this ability. Currently MADIDA works with Silicon Graphics primitives, the "C" programming language, and an electronic mouse. The last major concern was to provide a relatively inexpensive tool that could run on relatively inexpensive hardware. Our goal is to provide a portable cost effective system for the maintenance and diagnostic domain. The cost of RuleMaster is $4,500 for a single user system and $17,500 for a multi-user system. RuleMaster is compatible with computers ranging from $2,000 for an IBM-PC (or compatible) to $500,000 VAX machines.

RuleMaster also can generate C and Fortran source codes. This can be used to produce real-time execution systems for use in on-board diagnostics as well as to port completed systems to PC class CPU's.

Extending RuleMaster With Uncertainty

Experts use examples to describe their decision making process when reasoning to a conclusion. The reasoning involved is often uncertain and non-monotonic in nature. This requires that the tool used to develop expert systems allow the knowledge engineer to associate degrees of uncertainty when presenting the examples to the system. The uncertain examples given by diagnostic experts necessitates the integration of inexact reasoning into RuleMaster.

In expert systems, evidence and hypotheses are often linked by rules. Each rule is associated with a number to quantify the certainty degree of the

rule. These rules are connected into an inference network, which is used by the system's inference engine to reason about the likelihood of the hypotheses. A simple inference network is:

```
              h(1)
               ^
               |
               |   r(1)
               |
               |
              e(1)
             ^   ^
            /     \
    r(2)   /       \   r(3)
          /         \
       e(2)          e(3)
```

where h = hypothesis, e = evidence, and r = rule.

To implement this idea into RuleMaster, each node (e, h) and each link (r) in the inference network will be implemented as a module that will be organized into a hierarchy similar to the inference network. Sequential and parallel combination modules will be integrated into the hierarchy to combine certainty factors in two different situations and return the combined certainty factor (CF).

The transition from one state to the next in a deterministic state automaton (DFSA) will require two additional actions to be carried out: (1) call its antecedent module, which returns the CF of the antecedent module, (2) call the sequential combination module to compute the CF of the inferred hypothesis from the antecedent's CF and the rule's CF.

CONCLUSIONS

The MADIDA system offers the maintenance and diagnostic domain an alternative to the two current types of testing procedures: manual testing and automatic testing. MADIDA can be incorporated into maintenance and diagnostic domain and offer a spectrum of increasingly automated diagnostic procedures. This spectrum will permit diagnostic testing to be carried out in a cost effective manner by allowing facilities various degrees of automation.

There are several project goals for 1987. Some of these goals are:

1. Implementation of an inference network into the existing hierarchy to integrate uncertain examples into the knowledge base.

2. Integration of additional diagnostic test procedures into the knowledge base, permitting board diagnosis to be performed at a lower level.

3. Coordination of several graphics data bases; as the diagnostic test procedure proceeds from board diagnosis to component diagnosis to chip diagnosis, etc., MADIDA can invoke the various graphics data bases to display the section of the circuit board currently under study.

4. Integration of MADIDA into the automatic test equipment environment. MADIDA's hardware will be physically connected to existing automatic testing equipment (ATE), and use the results from the ATLAS program to perform lower-level diagnostic test procedures. Also, we hope to use some of the ATLAS primitives to get readings from the circuit board under test and then incorporate the data into MADIDA's decision making process.

5. Currently, MADIDA encodes only surface level knowledge. In the future, we hope to integrate deep-level domain knowledge into the system and have these two forms of knowledge representation work in conjunction with each other.

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